DOCUMENT RESUME

ED 129 563 SE 019 037

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TITLE	Scientific Literacy and a Framework of Science.
PUB DATE	Feb 75
NOTE	23p.; Paper presented at the annual meeting of the National Association for Research in Science Teaching (48th, Los Angeles, California, March 17-20, 1975); Contains occasional light and broken type
EDRS PRICE	MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS	*Citizenship Responsibility; Educational Research; *Educational Responsibility; *General Education; Instruction; Literacy; *Science Education; Scientific Attitudes; *Scientific Literacy
IDENTIFIERS	Research Reports

ABSTRACT

Science teaching for scientific literacy and science in general education are discussed. Fifteen aspects of a literate citizenry are discussed and related to methods of science teaching. Also discussed are eight factors that define scientific literacy and the relationship of scientific literacy to the general literacy that educators provide. (MH)

February 10, 1975

Scientific Literacy and a Framework of Science

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To accept an invitation to present any phase of the topic scientific literacy requires an individual with rather unique but probably not exceptional characteristics. After accepting the invitation and reflecting upon the task, I searched myself for unique qualifications and I think I found at least one characteristic. It is ignorance. The next concern was to try to explain away my ignorance or to find company in it. In the search I found a comment by Sylvain Bromberger that phrases it better than I.

> "I am a very ignorant person and I have long assiduously deplored this fact. Ignorance is an invitation to scorn; it presumably deprives one of all sorts of joys, it can't be put to any useful ends, it can't be eaten, it can't be given away, and it is damn difficult to get rid of in any other way. Only those who are totally ignorant about ignorance can believe that 'ignorance is bliss'. But, ignorance can also define and determine the value of scientific contributions. Its study should therefore be one aspect of the study of how scientific contributions can be assessed, and it should thereby become part of the philosophy of science. This fact, if it is a fact, holds a heartening hope for someone like me. It means

that a cause of shame and embarrassment may yet turn out to be a source of professional expertise! My talk should be followed in the light of that hope. Dale Carnegie, that great existentialist, somewhere quotes Robert Maynard Hutchins, that great essentialist, in turn quoting Julius Rosenwald, that great former president of Sears and Roebuck, as saying: "When you have a lemon, make a lemonade." This is what I propose to do here, and I invite you to share the refreshment, sour though it may turn out to be."

(Nagel, Bromberger, and Brunbaum -- Observation and Theory in Science -- Johns Hopkins Press, Baltimore and London, 1969. Pages 45-46.)

Educators generally agree that science plays an important role in general education, but why it does, how much science, what science, where in the curriculum it should occur, how science should be taught, and what specific contributions it makes, are producing volumes of dispute, only a trickle of ideas, and no principles of reasonable credibility. We are besieged with volumes of opinion based expositions and one time "research studies" that hardly qualify as pilot studies relating to what and how science should be taught.

Vocabulary selected, at times indiscriminately from science, engineering, and philosophy for use in science education has been prostituted to the point where any one word, regardless of context represents as many concepts as people who use it. Advertising psychology in the form of catch phrases or words has been substituted

for 1) objective examination of the structures and functions of science, 2) how these relate to what little is hypothesized about how people learn, and 3) the relationship between experiential maturity and complexity of learning. To some groups the objectives for science education are cognitive, to others the objectives are conceptual, and to still others the objectives are a mixture of cognitive and conceptual. It is speculated that all groups have at least one objective that is affective in nature. Reference is made here to such terms as "inquiry learning", "discovery learning", "learning how to learn", "problem solving", "concept learning," "humanistic education", "critical thinking", "scientific attitude", etc.

This attempt to sell the teaching of science using the "topless" approach has brought science education to its knees. The claims of science education have not and in most cases cannot be demonstrated. The research that has been carried on cannot be replicated so it has not been replicated. Because of the inadequacies in conceptual vocabulary and frames of reference for assessment the results of our research are contradictory. The phrase "no significant difference" predominates.

These comments should not be offensive to specific individuals, we are all at fault because we have committed the age old misdemeanor; we have moved ahead to develop the subject "science education" before the foundations of science education were established. This is somewhat disquieting intellectually but not nearly as disquieting as the breadth assumed by science education. Science education has come to include empirical science, philosophy of science, history of science, applied science, sociology of science, science and society interactions, ethics of science, psychology of cognitive development,

psychology of affective development; indeed all of pedagogy and educationese and all of common sense. Science education has laid claim to the development of personal intellectual honesty, improvement of judgment, freedom from utilizing unfound beliefs in decision making, desirable attitudes, appreciations, creativity, improvement of general morality, etc. There has frequently been the failure to distinguish between the teaching of science and the practice of science. The sincere teacher of science is aware that the benefits to be derived from possession of knowledge of the substantive and regulative principles of science are limited for the individual and society. It seems rational to limit the claims of the benefits of such knowledge to the possible functions of science.

It is known that there is nothing more difficult than the transmission or development of general ideas as distinct from pretentious phrases. No person with reasonable sensitivity can confront a class many times without becoming aware that sound teaching is concerned with definite achievement on the part of the pupils. Vague generalizations are easily claimed but the achievement of these by students is difficult if not impossible to demonstrate. Achievements by the teacher and pupil are most easily demonstrated when the individual steps in the learning are known.

In science the steps at the elementary and secondary levels may be as follows: 1) the development of empirical concepts (this may be essentially naming the experiences, phenomona or events observed at the level desired -- descriptive, comparative, or quantitative); 2) noting the relationships between experiences or events and stating these relation-

ships utilizing the concepts and some connective terms. These relationships may be called empirical laws and the laws may be stated and learned at the descriptive, comparative, or quantitative levels; 3) in some cases the move may then be to the development of theoretical concepts and theoretical laws under which the empirical laws may be subsumed.

You note here the dependence upon many of the positivists philosophers views of concepts, laws, and theories. You may disagree, with this view, however, if you do; you should be able to form a structure that is helpful utilizing your accepted view. Further illustration of individual steps in learning may be found in the case of grammar where the precise status of each word in a sentence determines the meaning of the sentence. The learning outcomes that are specifics can be easily tested for.

Science teaching for literacy or science in general education has another kind of concern. Science teaching for literacy must refer to education for those who are capable and desirous of a general or liberal education. What are the prerequisites for a general education other than the desire? A risky answer is brains, character, and intellectual interest. These you recognize as being of unknown origin. They do not come with wealth, color of skin, or religion. Where does the population come from? Happily one can say that this combination of character, average brains, and interest in the present and future makes up the majority of the population.

In any educational consideration it is necessary to recognize that we are living through a period of upheaval in the scholastic world. We are in the midst of what may be called a period of educational chaos or even educational revolution. This condition is caused by the

dying away of "classical education" motivated by the once important characteristic of the educated person -- to know some mathematics, literature, history, science, and to fit the mold of the ethical character. There seems to be an abandonment of the importance of being able to express one's thoughts on subjects when the thoughts have a foundation in past culture, that is in knowledge. There seems to be preference for unfounded opinion. This could probably be expressed as a movement from pragmatic or realistic opinion to idealistic or existentialist. At a higher level of flattery one may say it is the replacement of a postiori logic with a priori logic.

Some of the changes are understood to be due to changes in the values held by the citizenry. The changes in values may be consequent to the truth that now the products of pure and applied science enter every texture of our thoughts. Some people do not like this. The methods and products of science color our literature and the solutions postulated for social and humanistic problems. Mechanical inventions in terms of gadgets, procedures, and decision making are traced to science as their originator. Some people do not like these either. The problems of living are no longer the home, the neighborhood, the community, the state, or the nation; they are the world. Provincal thought is now impracticable if not impossible. It must be recognized that the classical ideas of education may be doomed.

In the past our solution to educational problems has been the keeping of the old and the addition of something new. The task of revising education has hence been impossible. Once there were Latin, Greek, and religion with reading, writing and arithmetic. Later added were the social studies, science, music, art, etc. The cafateria line offerings were constantly increased with some parts of the bill of

fare required. Now the move is to have fewer and fewer requirements. Once it was believed that from the study of scholars and the scholarship of scholars the student gained that something that produced ideas, creativeness, the ability to make good judgments, and above all to be cultured and literate. Mathematics, for example, first studied as a collec tion of ideas, was gradually divested of all discussion of ideas and reduced to the mastery of formal methods of procedure. The approach became mechanistic and the product was judged merely on how it could be used. It may have been that the study of mathematics was changed from a cultural subject to that of a relevant subject. Could these terms be too strong? Maybe mathematics became too civilized for its real good in the education of youth or maybe the concept of "real good" changed. The meaning may have turned to functional or technological mathematics.

Within the disciplines encountered by youth are those that are to develop pure logic and those that are to develop rational thought. Mathematics, as previously stated, is or was a logic form that developed some mechanistic applications to become applied mathematics and hence the way it is used in the technological life of today. The concept of a priori logic that is the foundation of idea type mathematics is a mystery to most teachers of mathematics. The term logic has become such a household word that it too has lost its meaning. There are those who say that science is purely logical when science gains little if anything from pure logic. Man learns nothing about nature from pure logic alone. Those who use the term logic freely in science would, in my judgment, improve their means of communication by replacing it with the term rational. Science is rational and rational thought is of great

service to science. In schools the use of rational thought probably is to come from the study of science. Yet I ask, is science taught as the means of developing a rational understandable universe? It is speculated that the concept of science held by most teachers today may be characterized by what one group has erroneously called "the processes of science," for example -- observing, classifying, predicting, inferring, experimenting, forming hypotheses, defining operationally, etc. and have no real concept of any regulative principles followed in the practice of science. These processes seem to imply to the teacher that the development of knowledge is mechanistic which, of course, is based on the assumption that we know the mechanism by which knowledge comes into being. Is it possible that someone really knows the proper admixture or ritual of "processes" that will lead to knowledge?

Maybe our greatest conem relative to logic and rationality is to help the pupils identify the irrational and illogical, to help pupils to recognize imprecise ideas when and as they occur. The present way of life, with the emergence of modern theoretical and applied science, is replete with "A need to be understood by people." Yet, there is nothing more distructive of true education than to spend long hours in acquiring ideas or skills that lead nowhere. Which path do we follow; the ideas and skills that lead to human and personal goals or those that are neither logically, a priori or a posteriori, or at times rationally useful? To ask the immature to grasp a concept or principle at a level that surpasses his maturity seems to be fatal to all intellectual vitality. It produces individuals who have a sense of incompetence to grasp meanings or to penetrate superficial meanings and individuals who develop a distaste for all ideas because they are looked upon as equally futile.

It is possible that the boredom with intellectual activities found in schools today is not because pupils are taught carelessly, but, rather because they have been exposed to or taught too many things which have no coherence with a train of thought that would occur to anyone, no matter how intellectual.

Some teachers look upon science teaching as the rational reconstruction of the steps that led the scientist to some new knowledge; to the 'discovery' of a new 'truth'. The plan of the reconstructed events may be historical in origin or from the imagination of the teacher. The confusion comes from the differences between what we really reconstruct and precisely what we desire to reconstruct. Let us consider only two possibilities: 1) Do we want to reconstruct the processes involved in the stimulation and release of the human inspiration (the formation of a hypothesis) that led to the knowledge development? Do we really have any insight into this process? It is doubtful that we do. Do we known where hypotheses come from? The authorities seem to be of the opinion that the origin of any original hypothesis is unknown, except to say that it is created in the mind of a person. Do all scientists consistently formulate original new hypotheses? It is doubtful that most practioneers of science formulate as many as one original hypothesis in a professional lifetime. Thus it seems that lessons in hypotheses formation are futile and frustrating. At the present time most of the activity by students going under the guise of hypothesis formation is that of simple deduction. 2) Do we want to reconstruct the events whereby the hypothesis may be tested or illustrated? These may be the activities performed in fact gathering processes. These are the events (facts) that are to be translated into knowledge. This is the way the

investigator is to find out if the hypothesis is a "discovery". Reflection upon this causes one to say that "in order for this methodological reconstruction to be successful it is also necessary to build into the reconstruction the thought processes or mental steps originally employed." It is obvious that at best these mental steps or processes are, if recorded at all, the result of the looking back at what the scientists did and hence there exists only a skeleton. The confusion and feelings of futility come when the learner is to play the part of the scientist in this scenario without having a chance to read the script.

Confusion and frustration come when the individual who is guiding the learning is convinced that there is a mechanical, logical, or rational method of having new ideas or that there is a mechanical, logical, or rational method of creating new knowledge.

It seems to be fatal to a learner when the teacher does not distinguis between science teaching and the practice of science. This does not mean that the science teacher should merely inform the learner as to the empirical and theoretical contents of the science library of knowledge. The teacher must help the learner come to see some of the empirical relationships in the universe and to understand how these relationships have come to be accepted as consistencies. The teacher must help the learners to understand how theoretical and empirical laws function in this "understandable rational universe". The learner must understand the regulatory principles, so that he may inderstand the substantive principles, so that he may understand natural phenomena, and so that he may explain natural phenomena or predict natural phenomenon.

The effect we want to produce in the pupils through the study of science is to generate a capacity to apply or develop ideas that relate to the real and the man made universe. We must cease looking upon applied

science and engineering as counter productive to science. Applied science and engineering are the real and relevant world of the young. They are the parts to be reckoned with. They are representations of the connections between science and the percieved needs of society. If you like it better we can say that the applied and engineering products are the concrete experience stage from which instruction may well be launched.

Because of these, the examples we select from become the backbone of our teaching. Science, as it exists today, is a body of knowledge that may be recorded in a library, a body of knowledge that may function in explaining natural phenomena, and/or a body of knowledge that may function in making predictions. The many regulatory principles of the scientists gain their respectability from the consequent products. To have the immature learner participate in drills of procedures that lead him to no product, may well serve to conceal any concept of science from him and may cause him to see that these skills he is to learn really do lead no where. He may thus come to see science as non-functional in his pragmatic life. He may come to see science as being non-functional in the problems of living he is caused to examine in his school. Note that there are many concepts of science, not just one. Science is not a process when a indicates only one. It is well known that the methods used in scientific study are variously described, but all conform to the regulatory principles.

It should be apparent by now to all practicing teachers and professional educators that any adjustment of the curriculum cannot merely be the addition or subtraction of a subject or merely saying that the subject should be taught. It is far better policy to search the relations of the content of the part of the curriculum to be modified to

the whole body of educational influences that are to mold the pupil. Teachers, all of us, usually delude ourselves relative to what is accomplished in our one or two hour sessions even if spent in the laboratory. First, consider the backdrop that what the pupils are often exposed to in science is in no way related to anything else they do in school all day unless it is to study science during a free period. Because of this, the pupils must be very adaptable and capable of shifting their intellectual gears from the past to the present or to something that does not even exist in their experience. Let us assume that the pupil is in the laboratory where the idealists say he is to 'discover'. In reality what does he really learn in this short time? The answer is -- in the one or two hours he will probably at best be exposed to one fact or a limited set of facts which may be only one example of an operational definition of a word (a concept) or it may be one incident of a law (an example of a consistency). This is most optimistic because if you watch students of high school age in the laboratory, you will note that about four fifths of the time in the laboratory is occupied in the apprehension of the succession of details since the pupil is a novice in terms of the needed manipulative skills. His further apprehension is what he should do with what ever data he is able to gather. The frustration comes when he is asked to observe and he has neither the benefit of a hypothesis to guide his observations nor a list of suggestions of things he might observe.

The term scientific literacy, like many of the other educational labels, may be altruistic in motive, however, it is interpreted by some as trying to sell science to all. I would therefore like to rephrase the issue to 'The Place or Function of Science for a Literate Citizenry."

To the scientist or potential scientist; science for the sake of science is adequate. During the period of the 60's when the public was conscious of and convinced of the importance of science in order to remain 'respectable' in the world, science for the sake of science was of necessity viewed differently than it seems to be at present. You will recognize that presently, when compared to as few as 10 years ago, there are more scientists entering the social arena via problems of the environment, as food production, maintenance of habitats and species, genetics, energy, etc. There are also more scientists being challenged relative to the possible social effects of the application of research results. To be a functioning citizen during the current era demands that one be able to read and interpret technical literature, because his welfare or his decisions should depend upon it. The citizenry is becoming doubtful of some science and technology expenditures. There is an apparent unwillingness to turn science and technology over completely to the scientists and engineers. Yet the youth appear to be turning science off. The youth of this nation and many other nations appear to be turning science off for a variety of reasons; one of which may be because science is still taught to produce big scientis and little scientists, rather than literate citizens. This turning off seems to be in direct contraposition to the needs of the citizens. This incongruity, however, does match with the common practice of excessive dependence upon personal unfounded opinion in decision making. Now each of these can be challenged, however, such challenges would be fruitless because the position assumed by the parties would depend upon the personal philosophies involved. This, as so often is the case, makes communication between opposing parties impossible.

In the past there have been statements relating the need for or the function of science for total literacy that were less than realistic based upon any concept of the nature of science or the possible functions of science and upon the possible capabilities of the science teachers now or in the future.

Today, a calculated risk is being taken through the use of some guesses. These cannot even be dignified as assumptions. The following guesses relate to some of the characteristics or activities of the literate citizen that are science related. These guesses relate to the present culture which involves a variety of value systems within a country and between countries with some values found commonly in all countries. Some of these are food, shelter, health, right to reproduce, share of the world resources, etc. It seems that specific "cultures" no longer exist in specific countries; the world has decreased in size in terms of some kinds of communication. The people of the world are interdependent for natural resources in the form of food, energy, health, fertilizers, minerals, etc. The people of the world are attempting to impose controls on each other as evidenced in family planning, population control, limiting supplies, resources, etc. The people of the world are attempting to guarantee what may be called the personal freedoms of self determination for all individuals. The people of the world are forming concepts or at least opinions of a world society. The people within countries are examining their life styles and demands as well as the life styles and demands of others.

The things people do, the things people use, the things people value, the things people depend upon, the things people in responsible positions use in making decisions are more science related now than

ever before. In some cases the decisions are in direct opposition to one body of empirical knowledge and conform to a second body of equally credible empirical knowledge. The library of knowledge in pure and applied science, however, is more often respected than denied in spite of its inadequacies.

Now for the reflections of my ignorance -- the guesses as to the needs of a literate citizen:

1. A literate U. S. citizenry is able to communicate within itself and with other citizens of the world relative to knowledge or ideas of the nature of natural objects and phenomena.

2. A literate citizenry is able to communicate within itself and with other citizens of the world relative to the utilization or control of natural objects and forces.

3. A literate citizenry is able to utilize respected empirical concepts and laws in its constant adjustment to the environment.

4. A literate citizenry is able to explain events in its environment in a rational manner.

5. A literate citizenry is able to predict events in its environment in a rational manner.

6. A literate citizenry is able to read accounts of developments by the scientific community.

7. A literate citizenry is aware of how empirical concepts and laws probably come into being.

8. A literate citizenry is aware of the difference between theoretical concepts and laws and empirical concepts and laws.

9. A literate citizenry can use theoretical laws in unifying (explaining) empirical laws.

10. A literate citizenry is aware of how theoretical concepts and laws come into being.

11. A literate citizenry is aware that the knowledge developed in the scientific community is probable rather than absolute.

12. A literate citizenry knows that theoretical and empirical laws are statements of postulated and/or observed relationships or uniformities respectively that are formulated utilizing vocabulary with conceptual meanings that may be descriptive, comparative, or quantitative, hence these laws may be descriptive, comparative, or quantitative.

13. A literate citizenry is able to translate experience with the natural world into knowledge. (The natural world -- observation involves perception and mental processes.)

14. A literate citizenry is aware of the regulatory principles accepted in the scientific community that are employed in the generation and application of empirical and theoretical knowledge.

15. A literate citizenry is aware that science is concerned with the empirical universe.

In summary it may be stated that a scientifically literate citizenry understands some of the knowledge library of science, knows some of the limitations and potentials of the contents of the library, knows how and when to apply the knowledge library, knows where the contents of the library come from, and knows some of the regulatory principles involved in knowledge production and use.

In your consideration of these ideas it is necessary that you utilize science and not education definitions of the terms: fact, empirical concept, empirical law, theoretical concept, theoretical law,

hypothesis, induction, deduction, understand, etc. It is granted that even among scientists and philosophers there are some slight differences of opinion in their definitions.

Surely you may be able to add to this list, since these are science restricted. There are probably more of these, and also many in the social studies and humanities. The only constraints that should be imposed upon any additions are: 1) it is possible considering the nature of the substantive and regulative principles of science, 2) it is possible to demonstrate the contribution of science to the item as described, and 3) it is possible for the science teacher.

Notice that so far only casual mention has been made of the 'scientific attitude'. Maybe this is an error, however, concepts such as these though plausible and promising concepts, have collapsed in operation because the underlying ideas as attitude, etc., have not been developed to the practical reliable level.

The place of science in literacy must thus be determined by its possible functions. These are repeated -- 1) The knowledge formulated as empirical and theoretical concepts, empirical laws, theoretical laws, and protocols of development may be filed as a library to which one may point as existing (knowledge for the sake of knowledge). 2) The knowledge library of science may function in explaining natural objects and phenomena. 3) The knowledge library of science may function in predicting natural structures and phenomena. 4) The knowledge library of science may be applied technologically.

Science for literacy thus has more than one facet. Science for literacy has a human frame of reference. Science for literacy now exists in a world society in which it has gained great respect as well

as some mistrust. Science for literacy must thus involve the total school and not just the science teacher.

It is suggested that school curriculum developers re-examine their actions, recognizing that the schools for the local community may be justified only to the degree that the pupils concept of the world is limited to the local community. As the pupils concept of world grows to include the nation and later the world or universe; school curricula will change to recognize the expanded interrelationships of man with man and man with natural objects and phenomena. The emphasis is on the utilization of knowledge developed in the scientific community in understanding the learner's world.

It does not seem frivolous or haughty to call your attention to some worldly problems that have existed to varying degrees since man entered and to point out that all of these problems have social, humanistic, and science implications. These are: food, shelter, protection from enemies, energy, health, land on which to exist, the right to reproduce, freedom from fear of natural phenomena, and control of the natural elements. Regardless of how these are examined one always comes to the conclusion that they involve natural forces or objects and the accumulated knowledge related there to.

In the absence of some uniform policy relative to the goals of the country or the world it will be extremely difficult to define operationally or to adequately research the topic of "what is adequate scientific literacy."

Let us recognize that all people cannot understand at the same level. There are some whose knowledge of the natural or man made universe will be limited to descriptions or classifications of direct or indirect

sensory experiences. There are others who will be able to operate with theoretical concepts and laws at the highest quantitative level. There is also an infinite number of levels of understanding knowledge in between. Let us try to adopt the policy of "to a learner according to his ability and from a learner according to his ability."

In any definition of "scientific literacy" or the place of science in "general literacy" the terms to be employed for operation are suggested to be:

Concepts - these make up the vocabulary of science and are recognized to be both empirical and theoretical and to exist at different levels of complexity sophistication and abstraction

Empirical Laws - these are the consistencies noted in the natural world and are verbalized utilizing the concepts, combining terms, and conventions

Theoretical Laws - these are postulated consistencies in the natural world

Regulatory Principles - these are the rules that determine the methods employed in developing concepts and laws as well as the criteria for their acceptance

Explanation - the subsuming of events under laws, either theoretical or empirical

Prediction - using facts and laws to forcast events

Science-Society Interaction - the uses of the products of science and the demands of society in terms of new products and areas of study as well as the demands of science in terms of support and opportunities to develop

Humanistic Implications - the historical development of knowledge and how it is interrelated with the culture

Presently, there is a great gap between the idea and reality of research in the area of scientific literacy. We have only begun to recognize the importance of general literacy in which science plays an important part. We must recognize that more is to be expected of the research than can be delivered in the limited amount of time with the talent and money available. Let us therefore concentrate our efforts in the areas where we have some knowledge and some expertise. We have some expertise: 1) in developing the conceptual vocabulary of people in science, 2) in developing different levels of understanding of some important empirical laws that are formulated in terms of empirical concepts, 3) in developing different levels of understanding of some important theoretical laws that are formulated in terms of theoretical and empirical concepts, 4) in developing the ability to use the laws in the explanation and prediction of natural phenomena, 5) in developing knowledge of some of the regulatory principles of scientific investigation, and 6) in developing some manipulative skills. Let us help people to understand what they know. This means that the knowledge that makes up the contents of the library of science becomes functional in the lives of people up to the maximum of its functions -- these are the description, explanation, and prediction of natural and man made phenomena. Let us strive to secure the cooperation of the total educational agency in developing a level and kind of literacy that relates to people. The science teacher can teach science, and the social

studies teacher can teach the social implications and the teacher of the humanities can teach the humanistic implications. This kind of plan seems very unrealistic in light of the size of schools and the isolationist practices of the teachers of the several disciplines.

It is proposed that scientific literacy cannot exist as a single entity. Rather it must be a part of general literacy to be of any value, therefore, literacy in science must move along with literacy in the social studies with literacy in the humanities with literacy in technology or the seeds will be falling on solid rock in a arid region.

Aristotle is credited with saying that "Education is an ornament in prosperity and refuge in adversity."

I suggest that the task of science education is to give a rational analysis of its potentials and procedures related to the achievement of these potentials. It is only rational that science education must relate to empirical and theoretical science. It is not to say that the science teacher is a scientist, since he is not; he is the interpreter of the knowledge and application of science to future generations.

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